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Improving Pork Shoulder Processing with a Digital Twin-based Inspection System: Utilizing X-ray Technology and 3D Imaging

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Introduction:

Pork is one of the most important meat products for the European Union, with the EU being the world's largest pork exporter. In 2020, the EU exported over 4 million tons of pork, with a total value of €7.7 billion (Eurostat, 2021). The largest pork-exporting countries within the EU include Spain, Denmark, and Germany.

However, despite the significant export value of pork products for the EU, the deboning process remains labor-intensive and manual. There is an interest in advanced automation of the processing chain to replace or assist the deboning operations. Thereto, inline inspection systems are explored that can analyze the bone structure of pork shoulders. A computed tomography (CT) system would be suitable as the X-rays can penetrate large volumes of meat resulting in high-contrast reconstructed 3D images of the meat and bone. Based on these 3D models a pork shoulder can be produced and fed to the automation system. However, CT systems have a few disadvantages such as their size and cost. Using prior knowledge of the pork shoulder, a 3D image can be rendered from a single X-ray projection assisted with input from a 3D camera and training data of the digital twin. Such a multi-sensor imaging system could be made much more simple and cheaper and would be easier to integrate into existing processing lines.

Method:

This Ph.D. research focuses on a new method involving a digital twin that uses a shape model of the pork shoulder's outer and bone shapes, both separately and combined. This approach allows for the use of a multi-sensor inspection system that can work with input from a 3D camera to fit a realistic 3D model of the pork shoulder to the measured point cloud. This shape model can then be used to simulate and improve the X-ray system.

Instead of relying on CT measurements, specifically trained neural networks are explored to predict the 3D bone structure from a limited number of 2D radiographs. This research created reference 3D models of the outer shape and bone using CT measurements of over 90 pork shoulders of different weight classes on high-resolution systems at the KU Leuven XCT core facility and a gantry CT system at UZ Leuven. Additionally, shape models have been developed to characterize the shape variance of pork shoulders to synthetically create more training data for the neural network.

Results:

At the moment, the developed digital twin is capable of simulating a multi-sensor system. It can simulate realistic X-ray images from various angles to inspect pork shoulders and simulate the use of a 3D camera to examine the pork shoulder from different viewpoints. By using the Fminc optimizer, this system can fit realistic 3D models that accurately represent the outer shape and inner structure from the simulated 3D camera view. The bone structure is predicted with an average mean squared error (MSE) of 6.94 mm on the test set and an overall average error of 9.80 mm on the combined shape of the test set.

Conclusion:

Based on these results, it can be concluded that the developed digital twin system can be an effective tool for simulating multi-sensor systems and accurately predicting the 3D structure of pork shoulders. The ability to simulate realistic X-ray projections and use a 3D camera to inspect the shoulder from various angles demonstrates the system's versatility and potential for use in various imaging applications.

However, currently, the error is calculated based on the simulated 3D camera data of the outer shape. These results will be compared to real 3D camera data collected on the inspection machine in the future to determine if domain adaptation will be necessary. Additionally, other possible fitting optimizers need to be explored to further improve these results.

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